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THE STANDING HEEL-RISE TEST IN PATIENTS WITH UPPER MOTOR NEURON LESION DUE TO STROKE

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ABSTRACT. The objective was to investigate the fatigue process in the triceps surae during the heel-rise test (eccentric and concentric phases) in comparison with a walking test and muscle strength. Eight men with prior stroke and 8 age-matched healthy men participated. The electromyographic activity in form of root mean square and mean power frequency of the gastrocnemius and soleus muscles were measured and work estimated. Walking speed and maximal peak torque were measured and differed significantly between the patient and reference groups. There were no significant differences between the groups nor legs concerning the number of heel-rises or work performed. In the eccentric phase, mean power frequency decreased significantly more in the gastrocnemius than in the soleus muscle in the reference group, while mean power frequency in the soleus muscle tended to decrease more, though non-significantly, in the affected leg. The conclusion is that the capacity to perform the heel-rise test in patients with prior stroke is better than plantarflexor peak torque and walking speed.

Key words: eccentric–concentric; electromyography; gastrocnemius; soleus; walking speed.

INTRODUCTION

The standing heel-rise test is a commonly employed clinical test (6, 13). The test consists of repeated eccentric and concentric muscle actions and reflects endurance rather than strength in the plantarflexors. Repeated eccentric–concentric muscle activities occur in many normal activities in daily living, i.e. during plantarflexion when walking and running. Fatigue has been defined as an inability to maintain the expected force or power output (5) and both central and peripheral factors may influence performance. It has been suggested that the shift in electromyographic spectral density towards lower frequencies indicates fatigue, being correlated to a reduction in propagation velocity along the muscle fibres (1, 11), as well as motor until recruitment, muscle activity level, modification of the action potential, firing rate, temperature and syncronization (for review, see Ref. 7). When the standing heel-rise test was performed until exhaustion in a group of 10 healthy young women, the gastrocnemius muscle showed a larger reduction in the mean power frequency (MPF) than the soleus muscle in the eccentric phase, while the soleus seemed to show a larger reduction in the MPF in the concentric phase (18).

In a stretch-shortening cycle (SSC), an eccentric muscle action is immediately followed by a concentric muscle action. The performance of the concentric action will be greater than that of a corresponding pure concentric action (10, 17). A study of the SSC using a dynamometer during plantarflexion in patients with upper motor neuron lesion showed higher concentric torque values after preceding muscle actions in both legs, and the percent increase was significantly higher in the affected (hemiparetic) leg as compared with the non-affected leg (18). We suggested that the higher performance of the affected leg was caused by better utilization of elastic energy in that leg owing to increased muscle stiffness.

In patients with hemiparesis after stroke, changes in muscle structures and metabolism have been reported (16). In a study by Edström (4), type II fibres showed atrophy of different degree and type I fibres usually remained unchanged. However, a changed motor unit activation may also lead to an increased type II fibres composition in the tibialis anterior, as well as in the soleus muscle in the affected leg (8). There are also reports of reduced aerobic capacity in the affected leg with reduced levels of an oxidative enzyme (14). Changes in passive stiffness of the affected ankle muscle tendon structure in hemiparetic subjects has been reported by Sinkjaer & Magnussen (15), who also demonstrated no changes in intrinsic properties, indicating that the functions of the cross-bridges were unaffected. The development of fatigue during the standing heel-rise test may therefore be different in patients with slight hemiparesis than in normals.

The purpose of the present study was to investigate the fatigue process during the standing heel-rise test, an eccentric–concentric test, in patients with prior stroke and healthy subjects, including frequency analysis of the electromyography and estimation of work performed. The heel-rise test was to be compared with walking speed and muscle strength.

Table I. *Characteristics of the patient group*

Age (years)	Diagnosis	Location	Time since lesion (months)
63	Hemorrhage	R Temporal	37
55	Infarct	R Temporal	40
56	Infarct	R Basal ganglia	37
56	Infarct	R Parietal	23
60	Infarct	R Temporal	44
61	Infarct	L Parietal	28
53	Infarct	R Parietal	18
51	Infarct	R Capsula Interna	8

R = right, L = left,

MATERIALS AND METHODS

Study groups

The inclusion criteria of the patients were: upper motor neuron disorder due to a first incident of cerebrovascular disease more than six months earlier, walking without assistive devices, and age between 50 and 65 years. The exclusion criteria were: more than one stroke or orthopaedic problems.

Eight male patients with previous hemiparesis (Table I) (1 right and 7 left), fulfilling the inclusion criteria, were selected from the Department of Rehabilitation Medicine at Sahlgrenska Hospital, where they had been patients. They had a mean age of 57 years (SD 4, range 51–63) and a mean weight of 82 kg (SD 10, range 64–98).

The patients were examined both by a physician and a physical therapist, and none had any clinical or subjective signs of spasticity in the ankle muscles, defined as increased resistance against passive muscle stretching or enhanced reflexes. On a modified Ashworth scale (2) all patients scored zero.

The reference group consisted of 8 healthy men with a mean age of 59 years (SD 3, range 55–64) and a mean weight of 82 kg (SD 14, range 60–102). The group was randomly selected from a database in which residents of the city of Göteborg born between 1915 and 1955 were registered. These persons were invited by mail to participate. The letter stated that they should not have had any orthopaedic problems or neurological deficits and, in their own opinion, have "good health". At least one person born each year was selected to be tested at a physical examination, for muscle strength performance on an isokinetic dynamometer, in the standing heel-rise test and in the walking test, in order to establish normal values. From this group we asked age-matched persons if they were willing to participate in the present study serving as a reference group. Testing of the right or left leg was randomized.

All participants gave their informed consent to take part in the study, which had been approved by the Ethics Committee at the Faculty of Medicine at Göteborg University.

Methods

A 30-metre walking test was performed twice (12). The person was first told to walk at a self-chosen speed and then, after a two-minute rest, to walk as fast as he could. The time was measured and the velocity calculated.

Torque of the plantarflexion at 60° per second was measured on a KINetic COMmunicator II dynamometer (Chattanooga Group, Inc., P.O. Box 489, Hixson, TN 37343, U.S.A.) with the subject in a prone and stable position (17). Three maximal pure concentric muscle actions were performed at the preset velocity of 60° per second, and peak torque was registered. After two minutes of rest, a combined muscle activity consisting of an eccentric muscle action immediately followed by a concentric muscle action was performed with maximal effort and the concentric peak torque was registered. The effect of a preceding muscle action (SSC) was taken as the percent difference between the concentric peak torque values.

The standing heel-rise test (6, 13) was performed with the subject standing on one foot on a 10° tilted wedge, that is, with the foot in a 10° dorsiflexed position. Footwear was standardized. The same shoe model in appropriate size was used by all participants in order to avoid differences in the performance of the test. For balance, the fingertips of both hands were touching the wall at the same height as the shoulders. A metronome was set to a beat corresponding to an angular velocity of approximately 60° per second. To measure the range of motion of the ankle joint during testing, an electrogoniometer (Penny and Giles Biometrics LTD, Gwent, U.K.) was attached to the lower lateral part of the right leg and the lateral edge of the sole. For technical reasons, when testing the left leg, the goniometer was attached to the medial side of the foot. A 90° angle of the ankle joint was defined as the point at which the sole of the foot was perpendicular to the axis of the lower leg. EMG activity was recorded with Ag/AgCl surface electrode discs with a diameter of 9 mm (Red Dot, 2239 monitoring electrodes, 3M Medica, Borken, Westfalen, FRG). After shaving and scrubbing the skin with alcohol two electrodes at a distance of approximately 30 mm were secured to the bellies of the gastrocnemius medialis and the soleus muscle in the direction of the muscle fibres. The reference electrodes were placed on the bony part of the medial and lateral parts of the knee, respectively. The EMG signal was preamplified with a gain of 1000, an input impedance of more than 0.5 MOhm at 50 Hz, a CMRR of more than 100 dB and a bandwidth of 0.5–400 Hz by a HDX-8? (Chattanooga Group, Inc., P.O. Box 489, Hixson, TN 37343, U.S.A.) and thereafter band-pass-filtered between ? and 490 Hz by a KC-EMG (Chattanooga Group, Inc., P.O. Box 489, Hixson, TN 37343, U.S.A.). The angle and the EMG were sampled at a frequency of 1250 Hz with a NB-MIO-16L9 (National Instruments Corporation, 6504 Bridge

Point Parkway, Austin, TX, U.S.A.) on a Macintosh computer with software developed in Lab View (National Instruments Corporation, 6504 Bridge Point Parkway, Austin, TX, U.S.A.) by Punos Electronic AB, Göteborg, Sweden. The EMG signal was then additionally band-pass-filtered using a Butterworth filter with cut-off frequencies of 10 and 300 Hz.

Before testing, the subject warmed up for 10 minutes with submaximal bicycling. A research physiotherapist conducted all tests and gave instructions and verbal encouragement during testing. After a couple of trials with one leg to allow the subjects to become familiar with the testing procedure, the heel-rise test was performed with the other leg. The subject was instructed to lift the heel as high as possible at the preset frequency until no further heel-rises could be performed, i.e. until exhaustion. In the group of patients the first leg to be tested was randomly selected and the test with the other leg took place approximately 10 minutes later. The heel-rise test and the strength measurement test were performed at two different occasions, with one week between the two tests. The walking test was performed before the heel-rise test.

Analysis

For the heel-rise test, the total work was calculated according to the formula:

$$W = m * g * l * \sum_{t=t_{start}}^{t_{stop}} \omega_t * \Delta t$$

where m (kg) is the weight of the subject, $g = 9.81$ m/s^2, l (m) is the length of the foot between the axis of rotation of the ankle joint and the metatarsophalangeal joints, and ω_t is the angle velocity between each sample. Δt is the time interval between each sample. The interval between t_{stop} and t_{start} is the time during which the calculation was made. Only the work calculated in the concentric phase was used in the analysis. The decrease in work between the first 10% and last 10% of the heel-rises performed was estimated.

The part of the EMG signal recorded when a velocity of approximately 60° per second was reached was *separately* derived for the concentric and the eccentric phases, by observing the angle of the ankle joint from the goniometer. The same range of motion was derived for all heel-rises for the same test. For each such part, the average of the amplitude of the rectified signal was calculated using the root mean square (RMS) method. Each part was modified by a Hanning window and a zero padder before Fast Fourier Transformation was used to obtain the mean power frequency (MPF). The development of the MPF and RMS was calculated with simple regression analysis, and then reported as percent decrease from the initial values. This was done separately for the concentric and eccentric phases. For all subjects the mean MPF and RMS value for each 10% of the test was calculated. The mean values for every 10% from all subjects were then normalized to the initial 10% value for each phase and muscle and plotted.

Statistics

Mean values and standard deviations are given in the description of the subjects. For results mean values and standard errors of the mean (±) are given and calculated using conventional methods. The Wilcoxon one-sample non-parametric test was used for differences between paired observations. Mann–Whitney's U-test was used for differences between groups. A significance level of 0.05 was used. The Spearman rank correlation coefficient was calculated.

RESULTS

Walking velocity for the self-chosen speed was 1.22 ± 0.05 metres per second among the patients and for the reference group 1.47 ± 0.05 metres per second. Walking velocity for maximal speed was 1.67 ± 0.10 metres per second for the patients and for the reference group 2.42 ± 0.09 metres per second. There was a significant difference between the patients and the reference group in both self-chosen speed ($p = 0.006$) and maximal walking speed ($p = 0.001$). The correlation coefficient between concentric peak torque and maximal walking speed was 0.82 ($p = 0.03$) in the patients for the affected leg and 0.87 ($p = 0.03$) for the reference group.

Peak torque measured on the dynamometer for concentric action of the plantarflexion at 60° per second was 43 ± 6 Nm for the affected leg and 59 ± 5 Nm for the non-affected leg. For the reference group, the peak torque was 63 ± 4 Nm. There were significant differences between the affected and non-affected legs ($p = 0.01$) and between the affected leg and the reference group ($p = 0.01$), but no significant difference ($p = 0.6$) between the non-affected leg and the reference group.

Peak torque for the combined muscle action in the eccentric phase was 98 ± 12 Nm for the affected leg and 116 ± 10 Nm for the non-affected leg. For the reference group, the peak torque was 122 ± 5 Nm. Peak torque for the combined muscle action in the concentric phase was 82 ± 11 Nm for the affected leg and 97 ± 10 Nm for the non-affected leg. For the reference group, the peak torque was 102 ± 5 Nm.

Percent increase in peak torque between pure concentric action and concentric action after eccentric action was $100 \pm 9\%$ for the affected leg and $68 \pm 8\%$ for the non-affected leg. For the reference group, the increase in peak torque was $64 \pm 12\%$. There were significant differences in this increase between the affected leg and the reference group ($p = 0.02$) and between the affected leg and the non-affected leg ($p = 0.01$).

In the heel-rise test, the mean total number of heel-

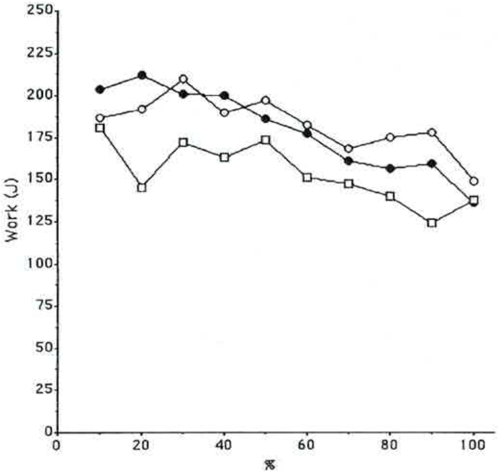

Fig. 1. Mean values of calculated work in the concentric phase during every 10th percent of the test in the reference group (●), the non-affected leg (○) and the affected leg (□) of the patients. The abscissa is in percentage of the number of heel-rises performed.

rises performed was 23 ± 2 for the affected leg and 26 ± 3 for the non-affected leg. For the reference group, the number was 24 ± 2 (left 23 ± 3 and right 25 ± 3). The mean total concentric work performed was 1534 ± 234 J for the affected leg and 1829 ± 435 J for the non-affected leg. For the reference group, the work was 1791 ± 187 J. The mean decrease in work during the test was 15 ± 10% for the affected leg and 8 ± 14% for the non-affected leg. For the reference group, the decrease was 28 ± 10% (Fig. 1). No significant differences ($p = 0.17$–0.63) were found between test legs. The correlation coefficient between concentric peak torque and total concentric work in the heel-rise test was 0.26 ($p = 0.49$) for the affected leg, 0.67 ($p = 0.08$) for the non-affected leg and 0.61 ($p = 0.14$) for the reference group.

The MPF in the *eccentric phase* decreased significantly ($p = 0.04$) more for the gastrocnemius muscle than for the soleus muscle in the reference group, as seen in Fig. 2. In the patients' non-affected legs, there were no significant differences ($p = 0.58$) between the muscles. In contrast, the soleus muscle tended to decrease more, though not significantly ($p = 0.07$), than the gastrocnemius muscle in the affected leg. In the *concentric phase* soleus and gastrocnemius showed similar decreases ($p = 0.50$–0.87) for both the hemiparetic patients and the reference group (Table II). No major changes occurred in the RMS during the concentric phase while decreases were seen during the eccentric phase (Fig. 3) (Table II).

DISCUSSION

Despite differences between the patients and the reference group in maximal single muscle actions and walking speed, no difference in performance in the standing heel-rise test could be demonstrated. Both patients and reference subjects performed an average of between 23 and 26 heel-rises. This is in agreement with Lunsford & Perry (13), who proposed that 25 repetitions would represent normal capacity in healthy subjects, regardless of age and gender. However, a different pattern in the decrease of MPF between the two muscles could be seen in the eccentric phase in the affected (hemiparetic) leg and the reference group. In the reference group, the decrease in the gastrocnemius muscle was larger than in the soleus muscle, whereas, in the affected leg of the patients, there was a tendency to a larger decrease, though non-significant, in the soleus muscle as compared with the gastrocnemius muscle.

As shown in the present study and in a study by Svantesson & Stibrant Sunnerhagen (18), the percent

Table II. *Percent change in mean power frequency (MPF) (SEM) and root mean square (RMS) (SEM) during the fatigue test.*

Values are seen for one leg for references and both the affected and the non-affected leg for patients. The changes are demonstrated for both the eccentric (E) and the concentric (C) phases and for the two muscles m. gastrocnemius (G) and m. soleus (S)

	MPF				RMS			
	ES	EG	CS	CG	ES	EG	CS	CG
References	−8 (2)	−18 (3)	−10 (5)	−9 (2)	−30 (9)	−24 (8)	−4 (6)	−1 (10)
Non-affected leg	−12 (2)	−14 (3)	−7 (4)	−9 (2)	−14 (9)	−17 (6)	+6 (2)	+4 (3)
Affected leg	−17 (2)	+2 (13)	−10 (1)	−16 (8)	−27 (9)	−33 (14)	−1 (5)	+3 (9)

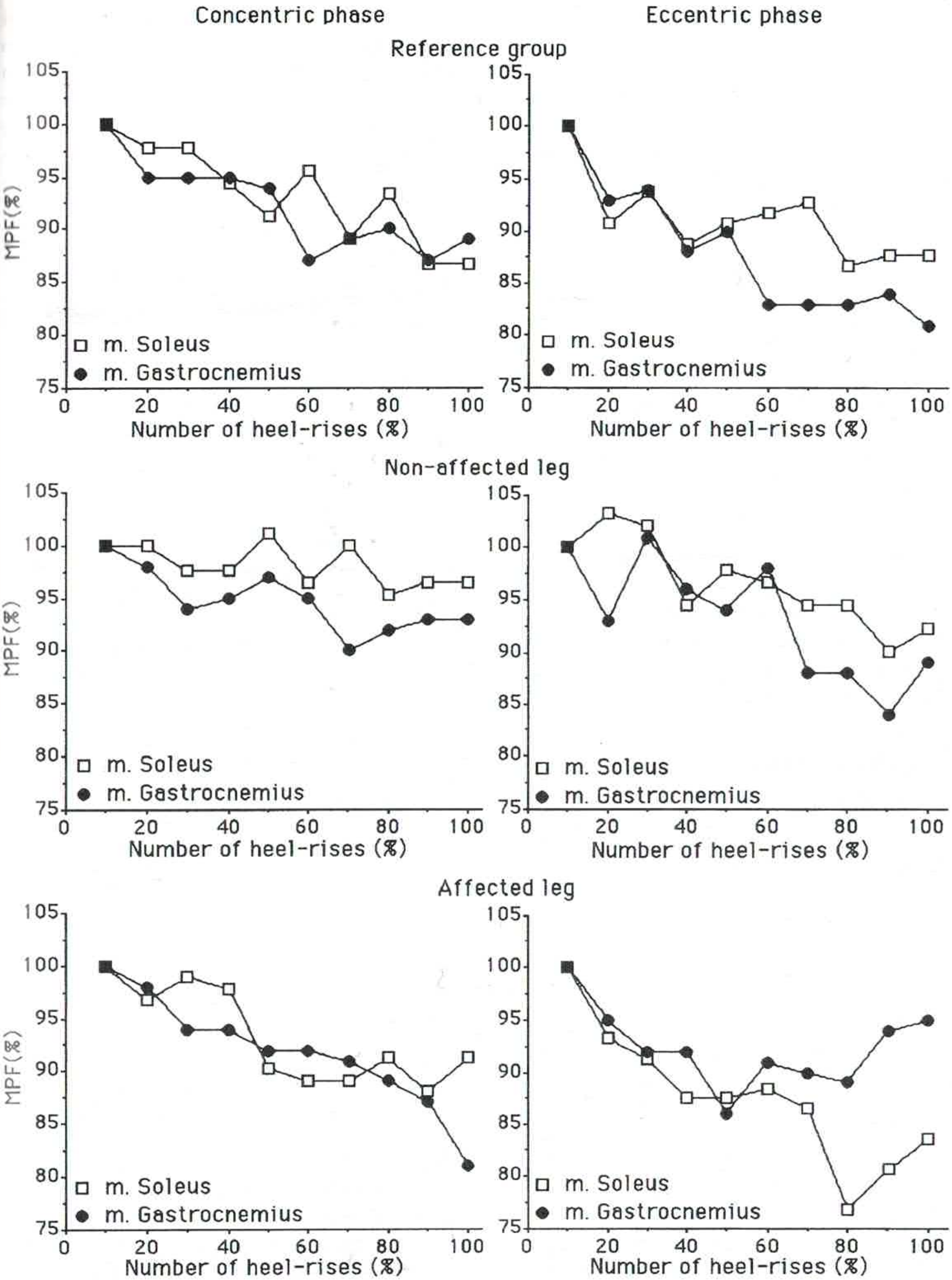

Fig. 2. Mean values (percent of initial values) for mean power frequency (MPF) in both the eccentric and concentric phases (shown separately) for the gastrocnemius and soleus muscles in the reference group, the non-affected leg and the affected leg of the patients. The abscissa is in percentage of the number of heel-rises performed.

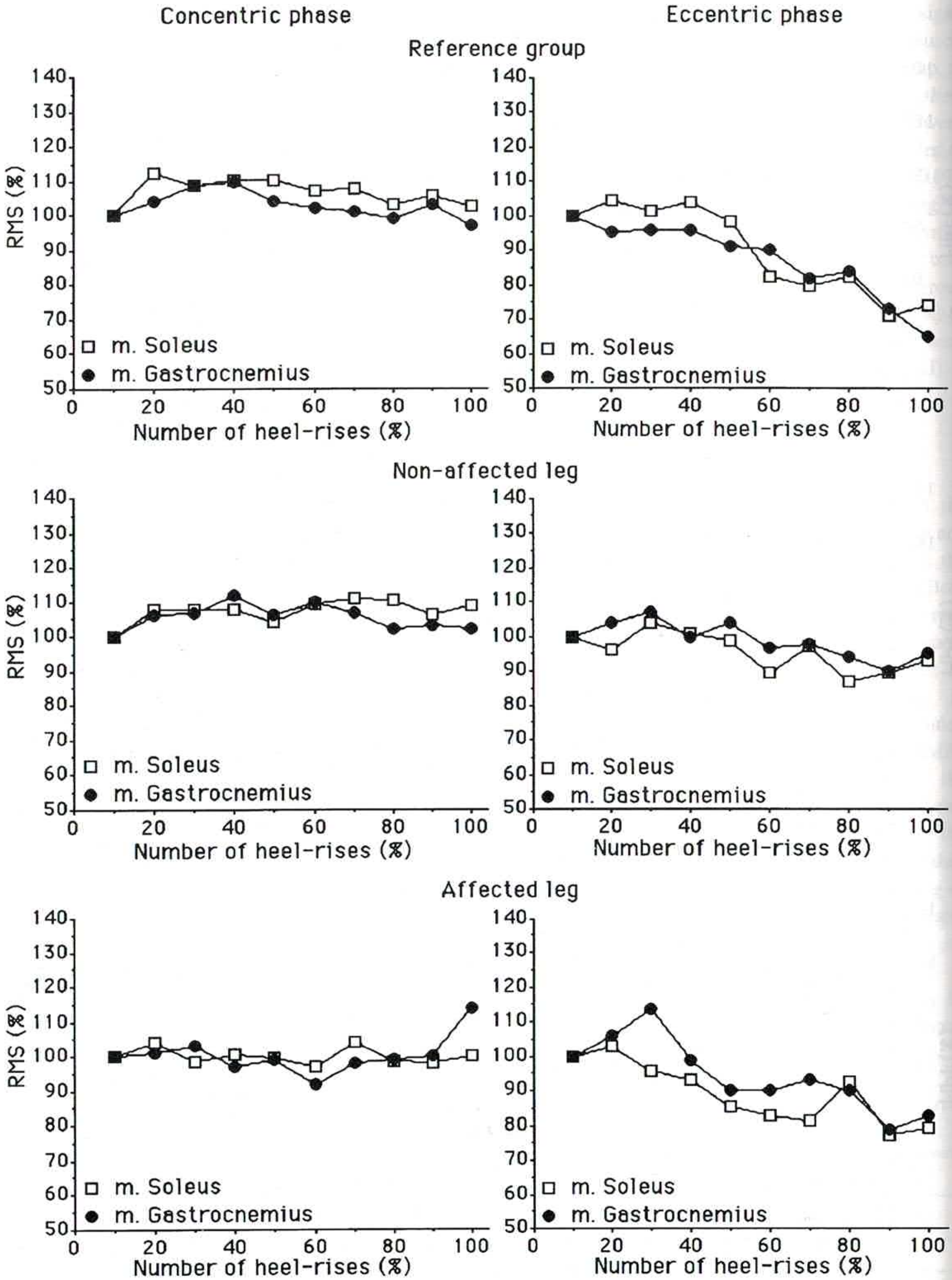

Fig. 3. Mean values (percent of initial values) for root mean square (RMS) in both the eccentric and concentric phases (shown separately) for the gastrocnemius and soleus muscles, in the reference group, the non-affected leg and the affected leg of the patients. The abscissa is in percentage of the number of heel-rises performed.

increase in concentric torque after a preceding eccentric muscle action was significantly larger in the affected leg as compared with the non-affected leg among stroke patients. We assumed that the higher performance in the affected leg was caused by better utilization of elastic energy due to increased muscle stiffness. Dietz & Berger (3) suggested that altered mechanical properties in the muscle contribute to muscle stiffness during locomotion in stroke patients. Sinkjaer & Magnussen (15) recently published a study in which passive muscle stiffness was seen to increase more than intrinsic stiffness, which is an indication that the function of the cross-bridges within the muscle was little affected. We believe that there is a slightly increased muscle stiffness, especially in the affected leg, which may lead to increased utilization of elastic energy in repetitive eccentric–concentric exercises.

In normal subjects, as in a previously studied group of healthy young women (19) and the present group of middle-aged healthy men, the gastrocnemius showed larger reduction in MPF than the soleus muscle in the eccentric phase of repeated SSC exercises. In contrast, the tendency in the affected leg towards a larger reduction of the MPF in the soleus muscle in the eccentric phase is noticeable. Thus, the motor control of the soleus muscle seems to be more susceptible to the changes that occur after stroke and can contribute to the results of the present study, even though no spasticity could be noted clinically.

Differences in walking speed but not in the performance of the heel-rise test between the patient and the reference groups may indicate different abilities to utilize preceding muscle actions and also that walking is a much more complex activity than the heel-rise test. Close correlation was found between peak torque for plantarflexion and walking speed but not between peak torque and total concentric work in the affected leg of the hemiparetic patient in the heel-rise test. Both muscle weakness and changed neuromuscular control influence the quality of the walking pattern. In walking, the effect of prior muscle action in the hemiparetic patient can be reduced at toe-off, since the mechanism normally used to build up tension in the triceps surae can be wasted in the "back-pull of the knee" (9). On the other hand, in a standing heel-rise test, the continuously repeated eccentric–concentric muscle actions may be sufficient to increase muscle stiffness to a level at which storage and utilization of elastic energy might be beneficial for enhancing performance in the paretic muscle. The heel-rise test, most likely, reflects the utilization of prior eccentric muscle actions and seems to be a suitable test, if performed in a standardized way until exhaustion, for evaluating plantarflexor endurance at slow motions. Differences between normal subjects and patients as well as differences between the affected and non-affected sides can give different information when measurements are made of maximal forces and endurance. Prior muscle actions could also be utilized in physical training and rehabilitation of hemiparetic patients. Training activities emphasizing eccentric–concentric exercises may result in more normal function in the affected leg.

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